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ELECTROPLATING APPARATUS

Field of the Invention

[001] The present invention relates to electrochemical plating (ECP) apparatuses and processes used to deposit metal layers on semiconductor wafer substrates in the fabrication of semiconductor integrated circuits. More particularly, the present invention relates to an elecroplating apparatus which includes a shield interposed between an anode and a cathode to reduce the electroplating deposition rate at the edge region of a substrate and facilitate deposition of a metal film having a substantially uniform thickness across the entire surface of a wafer.

Background of the Invention

[002] In the fabrication of semiconductor integrated circuits, metal conductor lines are used to interconnect the multiple components in device circuits on a semiconductor wafer. A general process used in the deposition of metal conductor line patterns on semiconductor wafers includes deposition of a conducting layer on the silicon wafer substrate; formation of a photoresist or other mask such as titanium oxide or silicon oxide, in the form of the desired metal conductor line pattern, using standard lithographic techniques; subjecting the wafer

substrate to a dry etching process to remove the conducting layer from the areas not covered by the mask, thereby leaving the metal layer in the form of the masked conductor line pattern; and removing the mask layer typically using reactive plasma and chlorine gas, thereby exposing the top surface of the metal conductor lines. Typically, multiple alternating layers of electrically conductive and insulative materials are sequentially deposited on the wafer substrate, and conductive layers at different levels on the wafer may be electrically connected to each other by etching vias, or openings, in the insulative layers and filling the vias using aluminum, tungsten or other metal to establish electrical connection between the conductive layers.

[003] Deposition of conductive layers on the wafer substrate can be carried out using any of a variety of techniques. These include oxidation, LPCVD (low-pressure chemical vapor deposition), APCVD (atmospheric-pressure chemical vapor deposition), and PECVD (plasma-enhanced chemical vapor deposition). In general, chemical vapor deposition involves reacting vapor-phase chemicals that contain the required deposition constituents with each other to form a nonvolatile film on the wafer substrate. Chemical vapor deposition is the

most widely-used method of depositing films on wafer substrates in the fabrication of integrated circuits on the substrates.

[004] Due to the ever-decreasing size of semiconductor components and the ever-increasing density of integrated circuits on a wafer, the complexity of interconnecting the components in the circuits requires that the fabrication processes used to define the metal conductor line interconnect patterns be subjected to precise dimensional control. Advances in lithography and masking techniques and dry etching processes, such as RIE (Reactive Ion Etching) and other plasma etching processes, allow production of conducting patterns with widths and spacings in the submicron range. Electrodeposition or electroplating of metals on wafer substrates has recently been identified as a promising technique for depositing conductive layers on the substrates in the manufacture of integrated circuits and flat panel displays. Such electrodeposition processes have been used to achieve deposition of the copper or other metal layer with a smooth, level or uniform top surface. Consequently, much effort is currently focused on the design of electroplating hardware and chemistry to achieve high-quality films or layers which are uniform across the entire surface of the substrates and which are capable of filling or conforming to

very small device features. Copper has been found to be particularly advantageous as an electroplating metal.

[005] Electroplated copper provides several advantages over electroplated aluminum when used in integrated circuit (IC) applications. Copper is less electrically resistive than aluminum and is thus capable of higher frequencies of operation. Furthermore, copper is more resistant to electromigration (EM) than is aluminum. This provides an overall enhancement in the reliability of semiconductor devices because circuits which have higher current densities and/or lower resistance to EM have a tendency to develop voids or open circuits in their metallic interconnects. These voids or open circuits may cause device failure or burn-in.

[006] A typical standard or conventional electroplating system 10 for depositing a metal such as copper onto a semiconductor wafer is shown in Figure 1. The electroplating system 10 includes a standard electroplating cell having an adjustable current source 12, a bath container 14 which holds an electrolyte electroplating bath solution (typically acid copper sulfate solution) 16, and a copper anode 18 and a cathode 20 immersed in the electrolyte solution. The cathode 20 includes a

semiconductor wafer 22 that is to be electroplated with metal. A contact ring 24 mounts the wafer 22 to the cathode 20.

[007] Both the anode 18 and the cathode 20 are connected to the current source 12 typically by means of suitable wiring 26. The electroplating bath solution 16 may include an additive for filling of submicron features and leveling the surface of the copper electroplated on the wafer 22. An electrolyte holding tank (not shown) be may further be connected to the bath container 14 for the addition of extra electrolyte solution to the bath container 14, as needed.

[008] In operation of the electroplating system 10, the current source 12 applies a selected voltage potential typically at room temperature between the anode 18 and the cathode 20. This potential creates a magnetic field around the anode 18 and the cathode 20, which magnetic field affects the distribution of the copper ions in the bath 16. In a typical copper electroplating application, a voltage potential of about 2 volts may be applied for about 2 minutes, and a current of about 4.5 amps flows between the anode and the cathode 20 and wafer 22. Consequently, copper is oxidized at the anode 18 as electrons from the copper anode 18 reduce the ionic copper in the copper sulfate solution bath 16 to form a copper electroplate on the

wafer 22, at the interface between the wafer 22 and the copper sulfate bath 16.

[009] The copper oxidation reaction which takes place at the anode 18 is illustrated by the following reaction equation:

$$Cu \text{ ----> } Cu^{++} + 2e^{-}$$

[0010] The oxidized copper cation reaction product forms ionic copper sulfate in solution with the sulfate anion in the bath 16:

$$Cu^{++} + SO_4^{--} \text{ ----> } Cu^{++}SO_4^{--}$$

[0011] At the wafer 22, the electrons harvested from the anode flowed through the wiring reduce copper cations in solution in the copper sulfate bath 16 to electroplate the reduced copper onto the wafer 22:

$$Cu^{++} + 2e^{-} \text{ ----> } Cu$$

[0012] When a copper layer is deposited on the wafer 22, such as by electrochemical plating, the copper layer must be deposited on a metal seed layer 23 such as copper which is deposited on the wafer 22 prior to the copper ECP process. Seed

layers may be applied to the substrate using any of a variety of methods, such as by physical vapor deposition (PVD) and chemical vapor deposition (PVD). Typically, metal seed layers are thin (about 50-1500 angstroms thick) in comparison to conductive metal layers deposited on a semiconductor wafer substrate.

[0013] Conventional electrochemical plating techniques use copper sulfate ($CuSO_4$) for the main electrolyte in the electroplating bath solution. The solution may further include additives such as chloride ion and levelers, as well as accelerators and suppressors which increase and decrease, respectively, the rate of the electroplating process. The rate of deposition of copper on the substrate, and the quality and resulting electrical and mechanical properties of the metallization, are largely dependent on the concentration of these organic additives in the electroplating bath solution.

[0014] However, one of the drawbacks of the conventional electroplating system 10 is that the current density at the contact ring 24 is higher than the current density at the central region of the wafer 22. Therefore, the plating film is thicker at the edge region than at the center region of the wafer 22. Thus, the thickness of the plating film electroplated onto the wafer 22 is non-uniform. Accordingly, a novel

electroplating device is needed to control the thickness of a metal electroplated onto the edge region of a substrate in order to facilitate a more uniform distribution of the metal across the edge and central regions of a wafer.

[0015] An object of the present invention is to provide a novel electroplating apparatus which is suitable for the electroplating of a metal on a wafer in the fabrication of integrated circuits.

[0016] Another object of the present invention is to provide a novel electroplating apparatus which facilitates control in the thickness of a metal electroplated onto the edge region of a wafer.

[0017] Another object of the present invention is to provide a novel electroplating apparatus which may include a mechanism to control the ion density of an electroplating solution in order to control the quantity of metal electroplated onto an edge region of a wafer.

[0018] Still another object of the present invention is to provide a novel electroplating apparatus which may include a shield positioned between an anode and a cathode/wafer to alter

the electric pathway between the wafer and the anode and improve the thickness uniformity of a metal layer electroplated onto the wafer.

[0019] Yet another object of the present invention is to provide a novel electroplating apparatus which may include a shield positioned between an anode and a cathode/wafer and a current source electrically connected to the shield to apply a selected negative or positive voltage to the shield and adjust the concentration of metal ions in an electroplating bath for the uniform deposit of a metal layer on the wafer.

[0020] Yet another object of the present invention is to provide a novel method for the uniform electroplating of a metal onto a wafer.

Summary of the Invention

[0021] In accordance with these and other objects and advantages, the present invention is generally directed to a novel electroplating apparatus which is suitable for depositing a metal layer of substantially uniform thickness across the center and edge regions of a semiconductor wafer substrate. The apparatus includes a reservoir for containing an electrolytic fluid. A cathode, to which is mounted a wafer, and an anode in

the electrolytic fluid are connected to an electroplating current source. A shield is provided between the cathode and anode to facilitate a more uniform deposit of the metal onto the wafer across the entire surface, including the center and edge regions, of the wafer.

[0022] The shield may have a ring-shaped configuration or a plate-shaped configuration and may be either electrically non-conductive or electrically-conductive. The electrically non-conductive shield alters the electric pathway between the anode and cathode in the electrolytic fluid. Consequently, the distribution of metal ions in the fluid, between the shield and wafer, is changed in such a manner that the thickness of a metal layer deposited onto the wafer is substantially uniform across the edge and center regions of the wafer.

[0023] The electrically-conductive shield may be connected to a shield current source. A switch may be provided between the shield current source and the shield. The switch may be manipulated to apply a negative charge to the shield, in which case the shield acts as a cathode and reduces the quantity of metal cations in the electrolytic fluid in the area adjacent to the edge region as compared to the area adjacent to the center region of the wafer. Consequently, the electroplating metal

deposition rate at the edge region is reduced to compensate for the normally lower metal deposition rate at the center region of the wafer, thus enhancing the overall thickness uniformity of the electroplated metal.

[0024] The switch may be manipulated to apply a positive charge to the shield, in which case the shield acts as an anode. Accordingly, the concentration of metal cations in the electrolytic fluid in the area adjacent to the edge region relative to the center region of the wafer is increased, to increase the electroplating deposition rate of the metal onto the edge region of the wafer, as deemed necessary. By the alternating application of positive and negative charges to the wafer using the switch, the thickness of metal electroplated onto the edge region of the wafer can be precisely controlled to provide a layer of electroplated metal having a substantially uniform thickness across the entire surface of the wafer.

Brief Description of the Drawings

[0025] The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

[0026] Figure 1 is a schematic of a typical conventional electroplating system;

[0027] Figure 2 is a schematic of an electroplating apparatus of the present invention;

[0028] Figure 3 is a top view of a ring-shaped shield element of the electroplating apparatus of Figure 2;

[0029] Figure 4 is a cross-section taken along section lines 4-4 in Figure 3;

[0030] Figure 5 is a schematic of another embodiment of the electroplating apparatus of the present invention;

[0031] Figure 6 is a top view of a plate-shaped shield element of the electroplating apparatus of Figure 5;

[0032] Figure 7 is a cross-section taken along section lines 7-7 in Figure 6; and

[0033] Figure 8 is a schematic of still another embodiment of the electroplating apparatus of the present invention.

Detailed Description of the Invention

[0034] The present invention has particularly beneficial utility in the electrochemical plating of copper or other metal

onto a semiconductor wafer substrate in the fabrication of semiconductor integrated circuits. However, the invention is more generally applicable to the electrochemical plating of metals including but not limited to copper on substrates in a variety of industrial applications, including but not limited to semiconductor fabrication.

[0035] The present invention is generally directed to a novel electroplating apparatus which enhances uniformity in the thickness of a metal layer deposited on a semiconductor wafer. The apparatus facilitates the electroplating of a metal layer having substantially uniform thickness across the entire wafer surface, particularly between the center and edge regions of the wafer. The apparatus includes a bath container having a reservoir for containing an electrolytic fluid. A cathode and an anode immersed in the electrolytic fluid are connected to an electroplating current source. The wafer is provided in electrical contact with the cathode, in the electrolytic fluid. A shield is provided between the cathode and anode to modify the electrical characteristics of the electrolytic fluid and provide a substantially uniform thickness of the metal electroplated onto the center and edge regions of the wafer.

[0036] The shield may be ring-shaped or plate-shaped and may be electrically non-conductive or electrically-conductive. In one embodiment of the apparatus, the shield is either electrically conductive or non-conductive and alters the electric pathway between the anode and cathode in the electrolytic fluid. This alters the distribution of metal ions in the electrolytic fluid in such a manner that the thickness of a metal layer deposited onto the wafer is substantially the same across the edge region and center region on the wafer.

[0037] In another embodiment of the apparatus, the shield is electrically-conductive and may be connected to a shield current source. A switch may be provided between the shield current source and the shield. When the switch is manipulated to apply a negative charge to the shield, the shield acts as a cathode and reduces metal cations in the electrolytic fluid in the area adjacent to the edge region of the wafer. This reduces the quantity of metal cations in the electrolytic fluid in the area adjacent to the edge region as compared to the area adjacent to the center region of the wafer. Consequently, the electroplating metal deposition rate at the edge region of the wafer is reduced to compensate for the normally lower metal deposition rate at the center region of the wafer. This

enhances the overall thickness uniformity of the electroplated metal across the entire surface of the wafer.

[0038] Upon application of a positive charge to the shield by manipulation of the switch, the shield acts as an anode. Accordingly, the concentration of metal cations in the electrolytic fluid in the area adjacent to the edge region of the wafer is increased, to increase the electroplating deposition rate of the metal onto the edge region of the wafer, as needed. By the alternating application of positive and negative charges to the wafer by manipulation of the switch, the thickness of metal electroplated onto the edge region of the wafer can be precisely controlled to provide a layer of electroplated metal having a substantially uniform thickness across the entire surface of the wafer.

[0039] The electroplating apparatus may further include a mechanism to control the relative position of the shield with respect to the wafer in the electrolytic fluid. By movement of the negatively-charged cathode/shield toward the wafer, the deposition rate of the metal onto the edge region of the wafer is reduced correspondingly. By movement of the negatively-charged cathode/shield away from the wafer, the deposition rate of the metal onto the edge region of the wafer is increased.

This mechanism can be used in combination with the switch to facilitate precise control of the relative thickness of metal electroplated onto the center and edge regions of the wafer.

[0040] The electroplating apparatus of the present invention may be used with any formulation for the electrolytic fluid, such as copper, aluminum, nickel, chromium, zinc, tin, gold, silver, lead and cadmium electroplating baths. The present invention is also suitable for use with electroplating baths containing mixtures of metals to be plated onto a substrate. It is preferred that the electrolytic fluid be a copper alloy electroplating bath, and more preferably, a copper electroplating bath. Typical copper electroplating bath formulations are well known to those skilled in the art and include, but are not limited to, an electrolyte and one or more sources of copper ions.

[0041] Suitable electrolytes include, but are not limited to, sulfuric acid, acetic acid, fluoroboric acid, methane sulfonic acid, ethane sulfonic acid, trifluormethane sulfonic acid, phenyl sulfonic acid, methyl sulfonic acid, p-toluenesulfonic acid, hydrochloric acid, phosphoric acid and the like. The acids are typically present in the bath in a concentration in the range of from about 1 to about 300 g/L. The acids may

further include a source of halide ions such as chloride ions. Suitable sources of copper ions include, but are not limited to, copper sulfate, copper chloride, copper acetate, copper nitrate, copper fluoroborate, copper methane sulfonate, copper phenyl sulfonate and copper p-toluene sulfonate. Such copper ion sources are typically present in a concentration in the range of from about 10 to about 300 g/L of electroplating solution.

[0042] Other electrochemical plating process conditions suitable for implementation of the present invention include a plating rpm of from typically about 0 rpm to about 500 rpm; a plating current of from typically about 0.2 mA/cm^2 to about 20 mA/cm^2; a plating voltage of typically about 2 volts and a bath temperature of from typically about 10 degrees C to about 35 degrees C. In cases in which planarity of the electroplated metal through chemical mechanical planarization (CMP) is necessary, a leveling agent may be added to the electroplating bath solution at a concentration of from typically about 5 mmol/L to about 5 mol/L.

[0043] Referring to Figure 2, an illustrative embodiment of an electroplating apparatus 30 of the present invention is shown. The apparatus 30 may be conventional and includes a standard electroplating cell having an adjustable electroplating

current source 32, a bath container 34 having an interior bath reservoir 35, a typically copper anode 36 and a cathode 38. A contact ring 40 holds a semiconductor wafer 42 that is to be electroplated with metal, against the cathode 38.

[0044] The anode 36 and cathode 38 are connected to the current source 32 by means of suitable wiring 33. The bath container 34 holds an electrolytic fluid or electroplating bath solution 44. The apparatus 30 may further include a mechanism (not shown) for rotating the wafer 42 in the electrolytic fluid 44 during the electroplating process, as is known by those skilled in the art.

[0045] A shield 46 is mounted in the bath container 34, beneath the contact ring 40, according to techniques known by those skilled in the art. In a preferred embodiment, the shield 46 is mounted on a positional adjustment arm 60 which is engaged by a positional adjustment motor 58. The positional adjustment motor 58 is operated to adjust the vertical position of the shield 46 in the bath container 34, and thus, the proximity of the shield 46 to the contact ring 24.

[0046] As shown in Figures 3 and 4, the shield 46 typically includes a ring-shaped shield body 48 having a central shield opening 50. The shield body 48 may be an electrically-conductive metal or a non-conductive material such as plastic or ceramic, for example. In the case of a non-conductive shield body 48, an electrically-conductive material 51 covers the surfaces of the shield body 48. Preferably, the electrically-conductive material 51 is copper.

[0047] As shown in Figures 3 and 4, typical dimensions for the ring-shaped shield 46 include a diameter 64 of typically about 150~200 mm; a ring width 65 of typically about 3~5 cm; and a thickness 66 of typically about 30~50 mm. These dimensions are compatible with an electroplating apparatus 30 which is sized for the processing of 300 mm wafers. However, it is understood that these dimensions may vary depending on the diameter of wafers to be processed in the electroplating apparatus 30.

[0048] An electrical contact 52, such as suitable wiring, for example, is electrically connected to the shield 46. A switch 54 is connected to the electrical contact 52. The switch 54 provides selective electrical connection between a positive terminal 56a and a negative terminal 56b of a shield current

source 56. Accordingly, in operation of the apparatus 30 as hereinafter described, a positive charge is selectively applied to the shield 46 by establishing electrical communication between the positive terminal 56a and the shield 46 through the switch 54, as indicated by the phantom lines in Figure 2. Conversely, a negative charge is selectively applied to the shield 46 by establishing electrical communication between the negative terminal 56b and the shield 46 through the switch 54.

[0049] Referring to Figures 5-7, an alternative embodiment of the present invention is shown wherein an electroplating apparatus 70 includes a shield 72 having a plate-shaped shield body 74, as shown in Figures 6 and 7. The shield body 74 may be an electrically-conductive metal or a non-conductive material such as plastic or ceramic, for example. In the case of a non-conductive shield body 74, an electrically-conductive material 76 covers the surfaces of the shield body 74. Preferably, the electrically-conductive material 76 is copper.

[0050] Referring again to Figure 2, in operation of the electroplating apparatus 30, an electrolytic fluid 44 is placed in the bath reservoir 35 of the bath container 34, with the anode 36 immersed in the electrolytic fluid 44. The wafer 42, having a metal seed layer 43 deposited thereon, is attached to

the cathode 38, typically using the contact ring 40, and immersed in the electrolytic fluid 44. The electroplating current source 32 is energized to apply a negative voltage to the cathode 38 and a positive voltage to the anode 36.

[0051] At the wafer 42, metal cations such as copper in the electrolyte fluid 44 are reduced to form metal atoms, which are electroplated onto the seed layer 43. However, due to the presence of the contact ring 40, the current density is higher in the area of the electrolyte fluid 44 which is adjacent to the edge region of the wafer 42 than in the area of the electrolyte fluid 44 which is adjacent to the center region of the wafer 42. Consequently, the metal deposition rate is typically higher at the edge region than at the center region of the wafer 42.

[0052] To reduce the electroplating rate at the edge of the wafer 42, the switch 54 is manipulated to establish electrical communication between the shield 46 and the negative terminal 56b of the shield current source 56. This imparts a negative charge to the shield 46, causing the shield to act as a cathode in the electrolytic fluid 44. Accordingly, metal cations adjacent to the shield 46 are reduced, forming metal atoms that are electroplated onto the shield 46. The concentration of metal cations in the electrolyte fluid 44 adjacent to the edge

region of the wafer 42 is therefore reduced, thus lowering the electroplating deposition rate of the metal onto the edge region of the wafer 42.

[0053] In the event that it is deemed necessary to increase the electroplating rate at the edge region of the wafer 42, the switch 54 can be manipulated to establish electrical communication between the shield 46 and the positive terminal 56a of the shield current source 56. This imparts a positive charge to the shield 46, causing the shield 46 to act as an anode. Accordingly, metal from the electrically-conductive material 51 (Figure 4) of the shield 46 is oxidized, causing metal cations to enter the electrolytic fluid 44. This increases the concentration of metal cations at the edge region of the wafer 42, thereby accelerating the electroplating deposition rate at the edge region of the wafer 42.

[0054] The electroplating deposition rate of metal onto the edge region of the wafer 42 can be further controlled by adjusting the proximity of the shield 46 with respect to the wafer 42. Thus, when the switch 54 applies a negative charge to the cathode/shield 46, the electroplating deposition rate at the edge region of the wafer 42 can be decreased, as needed, by moving the shield 46 into closer proximity to the contact ring

40. Conversely, when the switch 54 applies a positive charge to the anode/shield 46, the electroplating deposition rate at the edge region of the wafer 42 can be increased, as needed, by moving the shield 46 into closer proximity to the contact ring 40. Positional adjustment of the shield 46 in the electrolyte fluid 44 is accomplished by actuation of the positional adjustment motor 58 and positional adjustment arm 60.

[0055] Referring next to Figure 8, in an electroplating apparatus 80 of still another embodiment of the present invention, the electrical contact 52, switch 54 and shield current source 56 of the embodiments of Figures 2 and 5 are omitted. The electroplating apparatus 80 includes a shield 82 which is interposed between the anode 36 and the cathode 38. The position of the shield 82 may typically be adjusted in the electrolyte fluid 44 by actuation of a positional adjustment motor 58 and positional adjustment arm 60, as heretofore described with respect to the embodiments of Figures 2 and 5.

[0056] The shield 82 may be an electrically non-conductive material such as plastic or ceramic, for example. Alternatively, the shield 82 may be an electrically-conductive material such as copper. Still further in the alternative, the shield 82 may include an electrically non-conductive shield body

(not shown) which is covered with an electrically-conductive material, as heretofore described with respect to the embodiment of Figures 2 and 5. Furthermore, the shield 82 may have either a ring-shaped configuration or a plate-shaped configuration.

[0057] In operation of the electroplating apparatus 80, the shield 82 changes the distribution of metal cations in the electrolytic fluid 44, between the anode 36 and the wafer 42, in such a manner that the electroplating deposition rate at the edge region of the wafer 42 is slowed down to substantially equal the electroplating deposition rate at the center region of the wafer 42. Consequently, the thickness of a metal layer deposited onto the seed layer 43 on the wafer 42 is substantially uniform between the edge and center regions of the wafer 42. The electro deposition rate at the edge region of the wafer 42 can be increased, as needed, by moving the shield 82 into closer proximity to the wafer 42 by operation of the positional adjustment motor 58.

[0058] While the preferred embodiments of the invention have been described above, it will be recognized and understood that various modifications can be made in the invention and the appended claims are intended to cover all such modifications which may fall within the spirit and scope of the invention.